Effect of Climate Change on Reference Evapotranspiration Based on Weighting Methods

Mohammad Javad Zareian[1], Saeid Eslamian[2], Hamid Reza Safavi[3] and Alireza Eslamian[4]

[1] Department of Water Engineering, College of Agriculture, Isfahan University of Technology, Isfahan, Iran, mj.zareian@ag.iut.ac.ir
[2] Department of Water Engineering, College of Agriculture, Isfahan University of Technology, Isfahan, Iran, saeid@cc.iut.ac.ir
[3] Department of Civil Engineering, Isfahan University of Technology, Isfahan, Iran hasafavi@cc.iut.ac.ir
[4] Department of Building, Civil and Environmental Engineering, Concordia University, Montreal, Canada, Corresponding Author, s_esla@encs.concordia.ca

Abstract

This study investigates the effects of climate change on evapotranspiration in the Zayandeh-Rud River Basin. The Isfahan weather station located in the East of the basin, was selected as the studied station. The combination of 15 GCM models was created based on the weighting method and based on the combined models, patterns of climate change including the ideal medium and critical ones were defined. Using the proposed patterns, the effects of climate change on temperature and evapotranspiration in Isfahan station were estimated under the A2 and B1 emission scenarios. The results showed that the annual temperature will increase between 0.63 to 1.13 °C in the eastern parts of the basin. Summer showed the maximum temperature increase. The A2 emission scenario shows more temperature increases in comparison with the B1 emission scenario. The results indicate that evapotranspiration increases by 3.1 to 4.8% in the basin. The results indicate the imbalance of agricultural water use in eastern part. In other words, the future conditions are difficult for the sustainability of water resources in the Zayandeh-Rud River Basin.

Keywords: Climate change, Evapotranspiration, Zayendeh-Rud River Basin, Emission Scenarios

1. Introduction

In general, climate change refers to unexpected changes in the properties of the Earth's climate that will happen in the long term (Goyal, 2004). These changes are mainly due to the expansion of human industrial activity that has occurred in recent decades. Due to the increasing development of industries in the world, the concentration of greenhouse gases in the atmosphere has increased dramatically. For example, the concentration of carbon dioxide has increased by 40% in the last century, and the forecasts indicate that it will continue in the coming years (Solomon, 2007).

As a result of climate change, climatic parameters have changed. The most obvious sign of this change is the increase in the temperature of the Earth. Global temperature over the last 100 years has increased by 0.74 °C and by 2100, the increase will reach 3 °C (Levinson and Fettig, 2014). Changes in the amount and pattern of precipitation are other phenomena that have been created as a result of climate change. These changes have occurred mainly due to the changes in the water content in the atmosphere (Eslamian et al., 2011a). Rainfall intensity fluctuated seriously as a result of climate change and the high intensity of rainfall is growing in the arid regions. Rare and severe floods and numerous droughts, indicate the devastating effects of climate change on the world's climate (Wang et al., 2011).

Apart from temperature and precipitation, evapotranspiration is another parameter that has fluctuated by the climate change. While, evapotranspiration is assumed as the main determinant of crop water requirements and any change in the rate of evapotranspiration will be changed the crop water requirement (Eslamian et al., 2011b).

Over the past three decades, many attempts have been made to quantify the effects of climate change on the meteorological parameters. The result of this effort was the establishment of the Intergovernmental Panel on Climate Change (IPCC). This foundation has provided General Circulation Models (GCMs). The downscaling methods were used to convert the GCMs outputs to daily time series of meteorological data. In these methods, the GCM outputs were combined with observed data in the meteorological stations and the time series data were generated for the future (Gohari et al., 2013; Zareian et al., 2014a).

So far, many researchers have attempted to estimate the future climatic parameters using a single GCM model. According to the results, the use of a single GCM model caused a great uncertainty in the prediction of climate change (Hawkins and Sutton, 2009). So, the researchers have recommended the use of combination methods to enhance the prediction accuracy of the GCM models (Guegan et al., 2012). Two general approaches have been proposed to combine these models. In the first method, the accuracy of the predicted probability of each GCM model is considered to be identical (Tao and Zhang, 2010). In the second method, the GCM models are weighted based on their ability to predict the climate parameters. The second method is more accurate than the first method, because should it have causes, the weight increase of the accurate models and these models will have more impact factor (Greene et al., 2006).

The GCM model results in 37 meteorological stations of Iran has shown that the climate change will reduce the precipitation in the arid regions and will increase precipitation in the humid regions of Iran (Abbaspour et al., 2009). In a study that was done to investigate the effects of climate change on the Zayandeh-Rud River Basin using the HadCM3 model, it was found that by 2100, the temperature of the basin will increase and the precipitation will decrease and these effects will be stronger in the final years of the 21st century (Massah Bavani and Morid, 2005). Gohari et al. (2013) reported temperature increase of 1.13 to 1.52°C and precipitation changes of -31 to 3.86% for 2015-2044 in this basin. Also, the temperature increases in the next centuries have been reported to be 3.5°C (Morid and Massah Bavani 2010).

This study evaluates the effects of climate change on the Zayandeh-Rud River Basin as one of the most complex areas in terms of water resources (Zareian et al., 2014b). The main approach of this study is using of the combination GCM models instead of the single models. Also, the different patterns of climate change will be presented for different conditions. Finally, by using the output of combination method, the effects of climate change on temperature and evapotranspiration on the Zayandeh-Rud River Basin will be discussed for the period 2015-2044.

2. Material and methods

2.1. Case study

In this study the Zayandeh-Rud River Basin, located in the centre of Iran, was selected as an example of arid and semi-arid regions. The basin has an area of 26,917 Km^2. Much of this area receives less than 150 mm of precipitation during the year. The main source of water in this basin is the Zayandeh-rud River which supplies the water requirements for uses that are mainly concentrated in the eastern part of the basin. Agriculture is the most important consumer of the water in the basin and needs about 73% of the consumption of the water resources in the region (Safavi et al., 2014). Development of the basin has caused the imbalance in supply and demand situation in water and has exacerbated the crisis of water shortages in recent years. As well as climate change, the situation is more complex for the area and thereby it influences the quality and quantity of water resources (Massah Bavani and Morid, 2005).

2.2. Selected weather stations

Due to concentration of more of water consumers in the central and eastern parts of the basin, the main pressure on water resources is in these regions. The most important use of water is for the irrigation and drainage networks that are located in the downstream of the Zayandeh-Rud dam. The Isfahan weather station is the indicator of the East Basin condition and was selected to investigate the effects of climate change on temperature data. This weather station has a longitude of 51°40’, latitude of 32°37’ and 1586 meters of elevation from the sea. Figure 1 shows the overview of the Zayandeh-Rud River Basin and the location of Isfahan weather station.

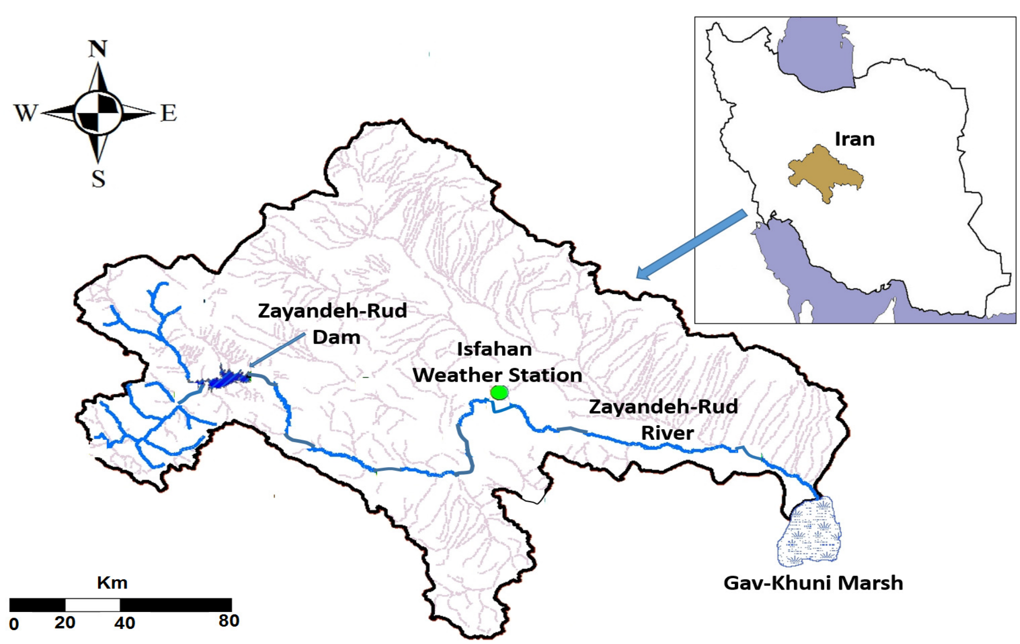

Figure 1. The overview of the Zayandeh-Rud River Basin and the location of Isfahan weather station

2.3. Selected GCM models

In this study, the output from 15 GCM models of Fourth Assessment Report of the IPCC (AR4) was used. Table 1 shows the details of the used model. The output of these models for the 1971-2000 (base period) and 2015 to 2044 (future period) was extracted from the IPCC Data Distribution Centre site. The outputs include monthly temperature data station at Isfahan weather station (Randall and Richard, 2007).

Table 1. Description of the 15 GCMs of IPCC's Fourth Assessment Report (AR4).

Model	Developer	Resolution	References
HadCm3	UKMO (UK)	2.5°×3.75°	Gordon et al. (2000)
ECHAM5-OM	MPI-M (Germany)	1.9°×1.9°	Roeckner et al. (1996)
CSIRO-MK3.0	ABM(Australia)	1.9°×1.9°	Gordon et al. (2002)
GFDL-CM2.1	NOAA/GFDL (USA)	2.0°×2.5°	Delworth et al. (2006)
MRI-CGCM2.3.2	MRI (Japan)	2.8°×2.8°	K-1 model developer (2004)
CCSM3	NCAR (USA)	1.4°×1.4°	Collins et al. (2006)
CNRM-CM3	CNRM (France)	1.9°×1.9°	Deque et al. (1994)
MIROC3.2	NIES (Japan)	2.81°×2.81°	Hasumi and Emori (2004)
IPSL-CM4	IPSL (France)	2.5°×3.75°	Marti et al. (2005)
GISS-E-R	NASA/GISS (USA)	4°×5°	Schmidt et al. (2006)
ECHO-G	MIUB/M&D (Germany)	3.9°×3.9°	Wolff et al. (1997)
INM-CM3.0	INM (Russia)	4°×5°	Diansky et al. (2002)
CGCM3-T63	CCCMA (Canada)	1.9°×1.9°	McFarlane et al. (1992)
NCAR-PCM	NCAR (USA)	2.8°×2.8°	Kiehl et al. (1998)
BCM2.0	BCCR (Norway)	1.9°×1.9°	Deque et al. (1994)

Equation 1 was used to determine the accuracy of each the GCM model in predicting the temperature at each weather station:

$$TE_G = \left| T_{BG} - T_{BO} \right| \qquad (1)$$

In equation 1, TE_G is the absolute error of each GCM models to predict the temperature. TB_G is the temperature output of the CCM models in the base period (19171-2000) and TB_O is the 30-years average temperature (1971-2000) based on the observation data in the Isfahan weather station.

The weight of the GCM models based on the estimated errors, obtained from Equation 2:

$$WT_G = \frac{1/TE_G}{\sum_{G=1}^{15} 1/TE_G} \qquad (2)$$

In Equation 2, WT_G is the weight of each the GCM model to predict the temperature changes that were calculated for each month.

2.4. Definition the climate change patterns in the future

The 30-year period 2015 to 2044 was selected to evaluate the effects of climate change. Extraction output values were made for two emission scenarios A2 and B1. A2 emissions scenario, affirms more rapid population growth coupled with low technological and economic development until 2100, while the B1 emission scenario divides the 21st century into two sections and claims that by 2050, the rapid growth occurs in population and socioeconomic and then will decline by 2100 (Solomon, 2007).

The monthly temperature changes for A2 and B1 emission scenarios were defined using equations 3 and 4:

$$\Delta T = \sum_{G=1}^{15} \left(WT_G \times \Delta T_G \right) \tag{3}$$

$$\Delta T_G = T_{FG} - T_{BG} \tag{4}$$

Where, ΔT is the future temperature change for the Isfahan weather station, ΔT_G is the 30-year average temperature changes predicted by each of the GCM models and T_{FG} is the average output of temperature for each of the GCM models in the future.

The ΔT values calculated from equation 3 for the use of all the GCM models have the highest accuracy for predicting the effects of climate change. Therefore, this value is considered as the average temperature change and was defined by the ΔT_m index (medium pattern of climate change). Then, the GCM models were reviewed again and the GCM models showing the temperature changes over ΔT_m were distinguished from the models and assumed as the critical models (critical pattern of climate change) and the other GCM models were assumed as ideal models (ideal pattern of climate change).

2.5. Downscaling of temperature data

The results obtained by GCMs outputs, only show the changes in temperature and precipitation. This is a property of the GCMs outputs and is due to their large scale characteristic (Semenov 2007). In order to use the GCMs outputs in metrological studies related to water resources, these should be converted to daily or monthly time series in each point using downscaling methods. The weather generators are used as a downscaling method here (Hashmi et al. 2011). LARS-WG (Long Ashton Research Station Weather Generator) is one of the most well-known stochastic weather generators that can produce daily time series of meteorological data. This generator gets the observed meteorological data in the baseline period and the climate change patterns as inputs and then predicts the daily time series of meteorological data in the future. This is based on semi-empirical distribution functions which can predict dry and humid periods in the future. To ensure the accuracy of the obtained meteorological data, this model makes some comparisons using Chi-square, t and F tests (Semenov 2008).

In this study, daily time series in the Isfahan weather stations are made for three climate change patterns. Each of the series includes the daily temperature data for 30 years.

2.6. Calculation of reference evapotranspiration (ET_0)

Most of the empirical equations that are used for calculating reference evapotranspiration require a lot of meteorological parameters such as daily maximum and minimum temperatures, relative humidity, wind speed and sunshine. So, in this study a different approach is attempted with a lower number of meteorological variables (T_{max} and T_{min}) to calculate the daily ET_0. So the Hargreaves-Samani method (Hargreaves and Samani, 1982) was selected to calculate ET_0 (Equation 5):

$$ET_0 = 0.0135 \times K_T \times R_a \times TD^{0.5} \times (T + 17.8) \quad (5)$$

Where: T_{max} and T_{min} are the maximum and minimum daily temperature (°C) respectively; $TD=T_{max}-T_{min}$ (°C); R_a is the solar radiation; T is the average daily temperature (°C); and K_T is an empirical coefficient, calculated using Equation 6:

$$K_T = 0.00185 \times TD^2 - 0.0433 \times TD + 0.4023 \quad (6)$$

3. Results

3.1. The GCM models weights

Figure 2 shows the results of the GCM models weighting to predict the temperature in Isfahan weather station. The results showed that the different GCM models have different accuracy for the prediction of temperature. CGCM2.3.2 model with the weight of 0.23 and NCARPCM model with the weight of 0.01 have the maximum and minimum accuracy in estimating temperature, respectively. In general, the GCM models with higher weight have lower frequency than other GCM models and the four models CGCM2.3.2, IPSLCM4, ECHAM5OM and ECHOG have alone 50% of the total weight of the GCM models.

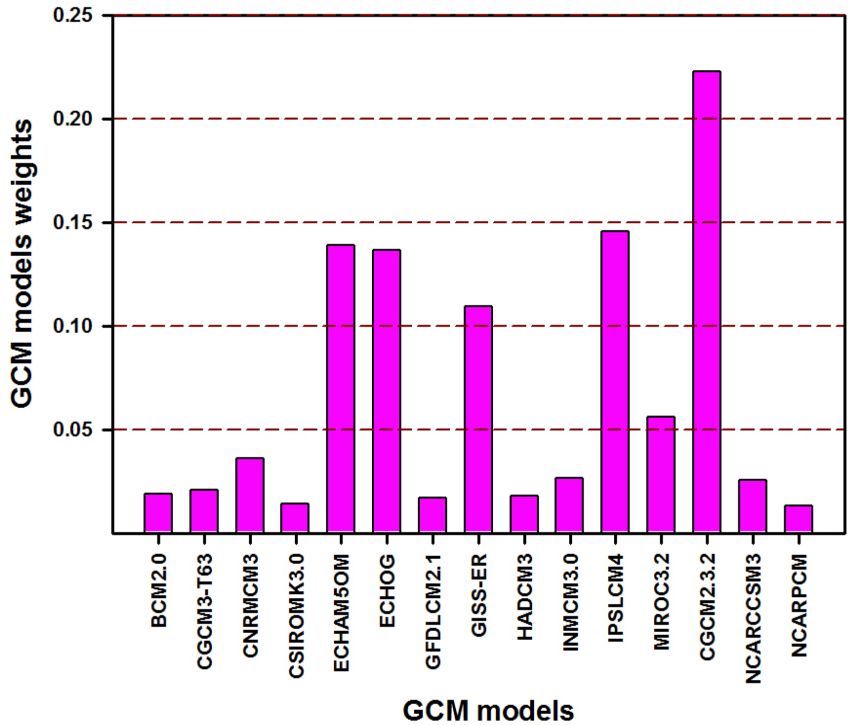

Figure 2. The GCM models weight for estimating temperature in Isfahan weather station

3.2. Temperature changes

Figure 3 shows the temperature changes of the Isfahan weather station. The results of the A2 emission scenario indicated that the temperature was increased between 0.1 and 1.1 °C in the ideal pattern, 0.4 to 1.4 °C in the medium pattern and between and 0.7 to 1.2 °C in the critical pattern. The values in B1 emission scenario for ideal pattern was between 0.1 and 1.3 °C, 0.4 to 1.6 °C in medium pattern and 0.7 to 1.8 °C in critical pattern, respectively.

Table 2 shows the seasonal and annual variations in temperature. The maximum temperature increases for both emission scenarios and three patterns of climate change, occurred in summer and autumn, respectively. The annual average temperature increase, varied between 0.63 to 1.13 °C in the A2 emission scenario whereas for the medium pattern, this amount was equal to 0.95 °C. For the B1 emission scenario, temperature changes varied between the ideal and the critical climate change patterns between 0.56 to 1.15 °C and in medium pattern it was equal to 0.86 °C.

Overall, the A2 emissions scenario showed more temperature increase than the B1 scenario.

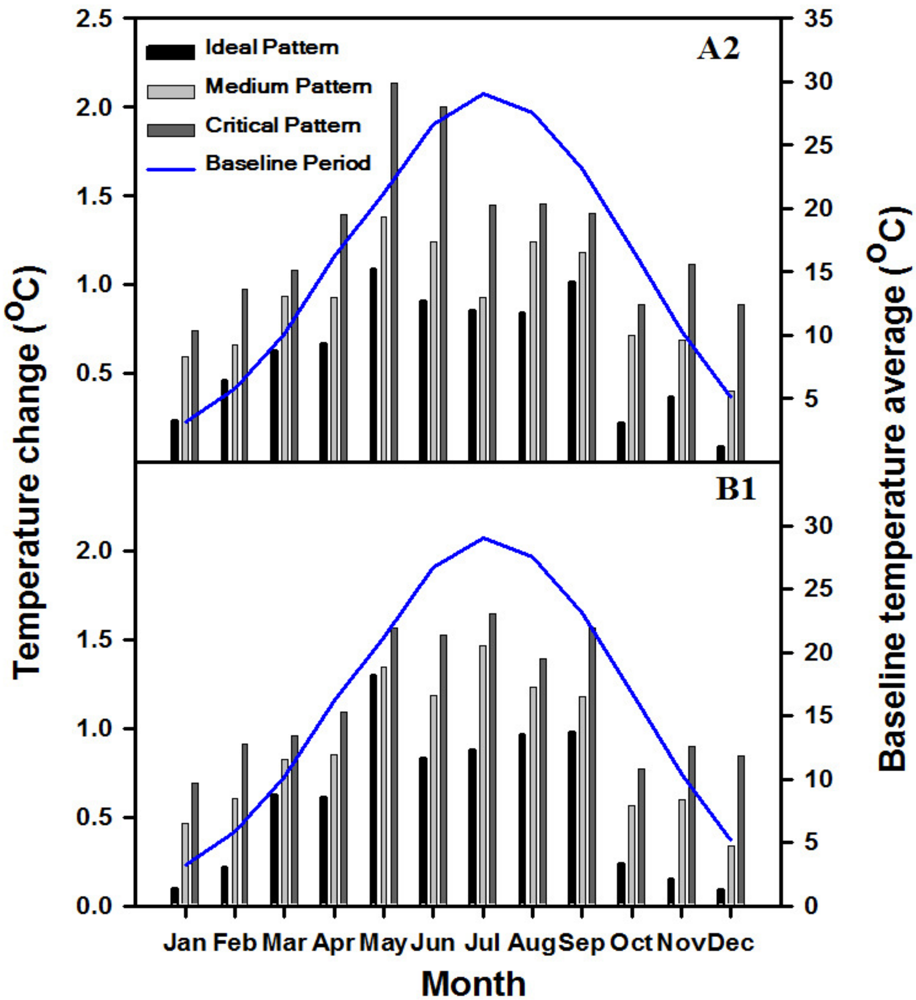

Figure 3. Changes in monthly temperature in Isfahan weather station

Table 2. Seasonal and annual temperature changes in Isfahan weather station

Periods		**Ideal Pattern**		**Medium Pattern**		**Critical Pattern**	
		A2	**B1**	**A2**	**B1**	**A2**	**B1**
Spring	Temperature Change (°C)	0.86	0.82	1.15	1.11	1.48	1.39
Summer		0.99	0.96	1.32	1.21	1.85	1.54
Fall		0.23	0.16	0.60	0.50	0.96	0.84
Winter		0.44	0.32	0.73	0.63	0.94	0.85
Annual		0.63	0.56	0.95	0.86	1.31	1.15

3.3. Reference evapotranspiration change (ET_0)

Figure 4 shows the changes in reference evapotranspiration of the Isfahan weather station. The results showed that the ET_0 will increase in all months of the year compared to the base period. The maximum increase in ET_0 in both A2 and B1scenarios is in September. Based on the A2 emission scenarios, the increase in ET_0 has changed between 6.8 to 7.7% in September, but in the medium pattern, this was 7.5%. In B1 emission scenario, the ET_0 increases for the ideal, medium and critical patterns were obtained as 7.3, 7.8 and 8.2% respectively. The minimum increase in evapotranspiration occurred in different months of the year and the minimum amount of ET_0 change, varied between 0.9% to 0.3% in A2 and B1 scenarios, respectively.

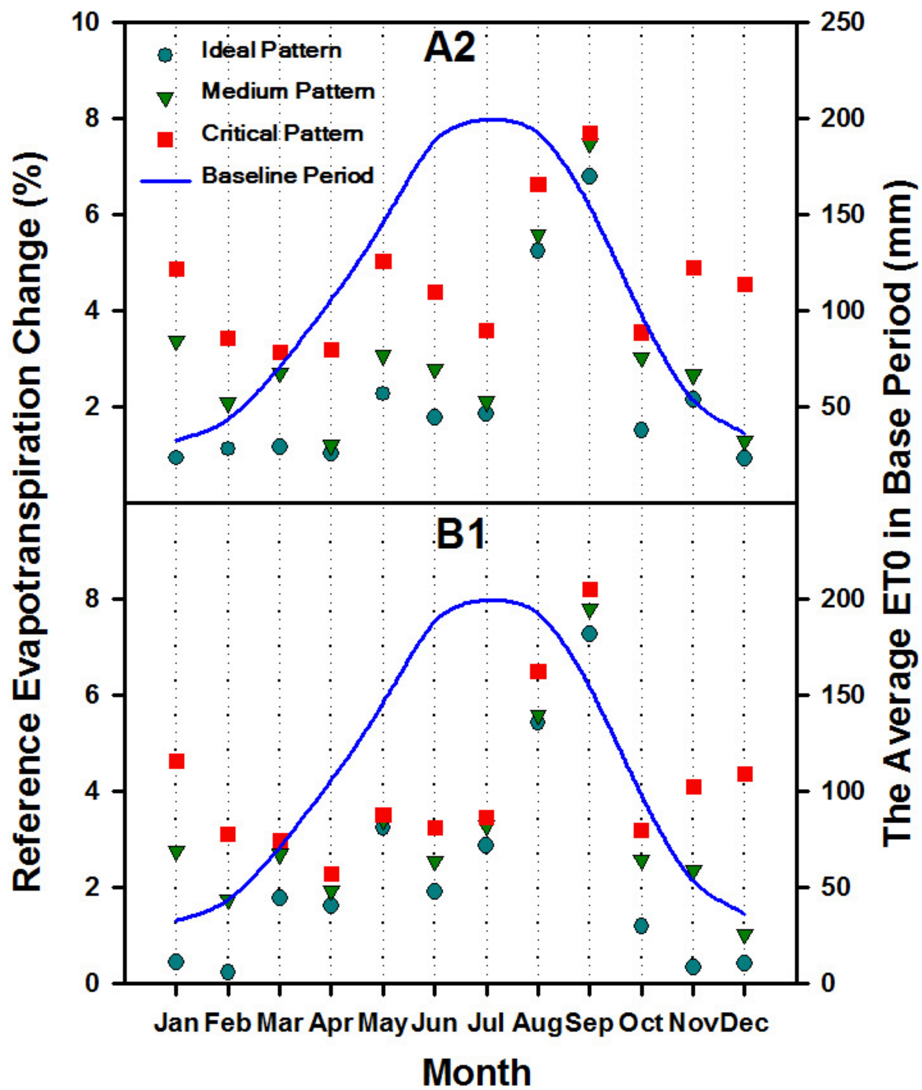

Figure 4. Changes in monthly reference evapotranspiration (ET_0) in Isfahan weather station

Comparison of annual reference evapotranspiration values also showed that the annual ET_0 will increase in all climate change patterns. The annual ET_0 in A2 emission scenario and in ideal, medium and critical patterns was obtained as 1361 mm (3.2% increase), 1372 mm (4.1% increase) and 1382 mm (4.8% increase), respectively. In B1 emission scenario, these values were 1359 mm (3.1% increase), 1367 mm (3.7% increase) and 1376 mm (4.3% increase), respectively. The A2 emission scenario generally showed more increase in reference evapotranspiration over the B1 emission scenario.

4. Conclusions

The results show that the different GCMs have different abilities in simulating the temperature changes. The CGCM2.3.2 model has the best precision for predicting temperature in the selected area in comparison with other examined ones. The overall results indicate that the temperature and evapotranspiration will increase in the eastern part of the Zayandeh-Rud River Basin. However, a large part of the agricultural land area is located in the eastern part of the basin. This can be a serious threat to the Zayandeh-Rud River Basin as it is one of the most complex areas of Iran in terms of water resources as this basin already faces many problems in providing water for the eastern part. Therefore, it is urgent to adopt strategies in this basin to cope with the problems caused by climate change in water resources.

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